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How Much Science Can You Have at Your Fingertips?

Abstract: Numerous suggestions are presented for helping men to learn and retrieve scientific information, with or without artificial aids.

In a discussion of how much information can be stored in a human brain, and how this compares with the amount of scientific information that has been published, it is argued that the number of "conceivable" states of the brain is much larger than the number of attainable states. It is necessary here to use a definition for the number of effective states of a brain or of any record.

It is mentioned that access to published literature is not the only problem in the communication of scientific information.

A discussion of how a man might acquire an encyclopedic knowledge emphasizes, for example, that a vital principle in learning and teaching is an explicit belief in the importance of general principles.

Knowledge is compared with a network having various impedances in the connections between the nodes, somewhat like a nervous system. Difficulties in classification (and in organization) appear when networks depart very much from having a tree-like structure. Some tentative suggestions for learning arise out of this model.

Possible new fields of research, such as *saporology*, and of new periodicals, such as *Half-Baked Ideas*, are touched upon.

A discussion of the value of mechanical aids concludes with a list of probable new advances in consulting scientific literature in the near future. Sixteen applications are listed for tape recordings of books.

The paper concludes with a warning that some of the world's greatest scientists have done their best work when they were given plenty of time to think their own thoughts.

The title of this paper is deliberately ambiguous. When we say that a man has knowledge at his fingertips we usually mean that he knows all the answers and can produce them rapidly without reference to machines or other people. But we could also mean that he could produce the answers quickly with artificial aid—by pressing keys and buttons, or by having a retinue of experts at his beck and call.

We may sometimes ignore methods of learning and think too much about artificial aids. If we are to evaluate artificial aids, it is worthwhile to consider what one can do without them, or without the more extreme forms.

I propose to approach this subject by considering the number of possible states of an individual brain. This is of course very speculative and may well be quite wrong.

There are supposed to be about 10^{10} nerve cells (neurons) in (the cortex of) the human brain,[1] each with $30 \overset{\times}{\div} 10$ connections (synapses) with other nerve cells,[2] rather crudely expressed. From these estimates we can estimate the number of possible states. I shall distinguish between the number of possible static states (in which the condition of the electrical pulses in the neurons or axons is ignored), and the number of possible dynamic states. I shall also distinguish between the conceivable states and the possible or attainable states, a distinction that will become clear in a moment. I shall also be writing about the effective number of states. If the brain is regarded as a continuous record, its number of states may be regarded as infinite. By the *effective number of states* of a continuous record I mean the antilogarithm to base 2 of the expected amount of information, measured in binary digits (bits), concerning whatever it is that is stored in that record.[32]

I shall assume that each synapse can have effectively ten states. The precise number here does not make much difference provided it is not utterly wrong. If it were a million instead of ten it would make a substantial difference, but not if it were two. It is a guess that the number is small.

On these assumptions the effective number of conceivable static states is about $10^{3\times10^{11}}=2^{10^{12}}$, equivalent to 10^{12} bits of information. The number of dynamic states is obtained by assuming that each axon can either have or not have an electric pulse in it. I am regarding time as discrete here and believe this assumption would not make much difference. So the number of conceivable dynamic states is $2^{10^{12}}\times 2^{10^{10}}=2^{10^{12}\times 1.01}$. This is about the same as the number of static states, after taking logarithms twice. Most of these states would not be symbolic of any sort of reality: in other words, most conceivable states of the brain would be quite mad. There are more ways of going wrong than of going right. A lot of them would presumably be substantially equivalent in the sense of leading to substantially the same activity, even if the states themselves were physiologically very different,[23] just as two different languages or symbolisms can have similar practical effects, or two different machine programs may effect the same calculation. Equivalent states of the brain are perhaps topologically identical, so to speak.

Of all these conceivable states of a brain only a small proportion would be possible in the sense of being attainable. This seems intuitively clear and can be checked by means of another approach. We can consider the rate at which information can be fed into the brain, and the rate at which the brain can modify its own state by thinking. If the input is reading, the maximum rate is about 25 bits per second.[4,31] At this rate the amount fed in for forty years at eight hours a day would be 10^{10}. Thinking would probably not add much to this. (In fact, the direct function of thinking is to handle information, not to generate it, at any rate if one definition of information is used.[29] Indirectly, thinking leads to the generation of new information and of course helps to determine the nature and importance of what is read, but these indirect effects probably do not undermine the present argument.) Presumably the number of possible states of the brain that can actually be reached by reading can hardly be more than $2^{10^{10}}$. It is comforting that apparently only a tiny fraction of the conceivable ways of being mad are actually possible.

Unfortunately these estimates are open to dispute. McCulloch,[18] citing von Foerster,[19] conjectured in 1949 that in a small, deep portion of the brain there may be as many as 10^{21} protein molecules, each capable of storing at least one bit of information. But that was nine years ago and I should not be surprised if McCulloch no longer believes it. If it is true, it may enable men to hold the machines in check should they become obstreperous.

These estimates can be compared with the potential capacity of printed books. The Library of Congress, with nearly ten million books, would have a capacity of say 10^{13} bits.[5] In practice the information in these books is highly "redundant," in the sense of information theory, but so is the information in the brain, and presumably to much the same extent if we are concerned only with reading as the input. It seems reasonable to suppose that one brain cannot hold as much as one thousandth of all printed knowledge.

But not all knowledge is equally important and not all of it is scientific. The London Science Museum Library has about 400,000 volumes, including 10,000 current sets of periodicals.[6] Perhaps a tenth of all publication is scientific. Most new knowledge appears in periodicals, so that 10,000 books a year is a fair measure of what you have to read to make sure of a comprehensive coverage. This ignores the backlog. But at a guess only a quarter of this is original, and of this quarter say a tenth is reasonably important.

If scientific knowledge were sufficiently well presented it begins to look as if one man with a perfect memory could know a reasonable fraction of what is important in science, and could know all of what is highly important. This proposition is intended to apply to each meaning of the word important, but not to all of them at the same time. I confess that the proposition does not really convey any information.

Access to published literature is not the only problem in the communication of scientific information. Consider, for example, the following statistical decision problem. Suppose we are testing some simple statistical hypothesis, such as that cosmic rays or atomic fall-outs have no effect on the mutation rates in mice. Suppose we have done an experiment and it reaches a significance level of 5 percent. Should we reject the null hypothesis? It may occur to us that the experiment may have been performed by other people without significant results. If these other experiments were taken into account the total significance of all the experiments combined may be negligible. Moreover the other results may have been unpublished because they were non-significant and therefore uninteresting. So we are left guessing even with immediate access to the published literature. This may be one reason why apparent medical advances often do not fulfill their early promise. The published statistics are biased in favor of what is interesting.

The next question is how a man could acquire an encyclopedic knowledge, what could help it and what prevent it. I shall first consider the question independently of artificial aids; or rather of *new* aids. Even books and stone slabs must have been regarded as artificial or supernatural when they were first introduced. Progress depends on artificial aids becoming so familiar that they are regarded as natural.

Perhaps the requirement that seems most obvious is a good innate memory, but I doubt if this is anything like as important as it seems. Thousands of chess players and card players develop a memory that seems phenomenal to

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a beginner. A good memory probably depends more on interest and incentives than on anything else.

Children are supposed to learn their first language faster and better than adults. I think this again is a question of incentives more than innate memory. A child who keeps making the same mistake is continually teased by his friends; an adult is not teased so much.

A vital principle in learning and teaching is a firm belief in the importance of general principles. General principles are often both obvious and overlooked. It may be conjectured that scientific ability (and perhaps even the I.Q.) depends largely on an early habit of thinking in terms of general principles, of forming abstractions, of attempting to generalize, of looking for analogies, of asking what is fundamental, and of repeated return to the elements (like the scales in music). Hilbert's recipe for mathematicians was "a lot of beginnings." By often thinking about what is usually taken for granted, like the fact that things fall, you may believe you can levitate, or you may invent a flying machine, or a law of gravitation. To the unusual all things are unusual.

It is surprising how many teachers forget to emphasize the fundamental points. They often go into turgid technical details, when the fundamental points alone would be of far more value.

Another important subject for the scientific generalist[30] is classification. There have been various attempts to classify knowledge in the form of a tree. In fact the organization of every university is such an attempt. The Universal Decimal Classification is another one. The difficulty of carrying out such a classification is exemplified by the subject of this symposium. The following headings in the Universal Decimal Classification are all relevant: Telecommunication, Linguistics, Education, Psychology, Bibliography, and Electronic Computers. These are at very different places in the classification.

Thus the tree of knowledge is a sort of banyan tree or rather a network. The network has nodes and roads. The roads are not all equally good; good roads correspond to strong associations. The strengths of the associations may be different along the two directions between two nodes. We can cope with this in our model by making each road one-way. We may think of the network as electrical with the roads having various impedances and with a valve in each road. Apart from the impedances we have what the topologist calls an *oriented linear graph*.

The use of the word *impedance* rather than *resistance* suggests a theory about the brain, though probably a wrong one. It suggests that the impedances along the nerve fibres or at the synapses may depend on the instantaneous frequency of the electroencephalogram. This suggests that if you have difficulty in remembering anything you should try switching to another frequency, which can be done, for example, by closing the eyes. The McCulloch-Walter theory about the electroencephalogram is quite different.[29] It seems likely that changes of resistance at the synapses can be achieved by biochemical mechanisms, so that the suggested mechanism may not be required, although its effect may not be the same.

Instead of representing fields of knowledge by nodes we could use the nodes to represent scientific propositions, or perhaps *atomic propositions*, an expression used by Wittgenstein though he probably never defined it.[21] (An atomic proposition can perhaps be best defined as any proposition belonging to a particular set, S, of propositions, S being *minimal*, i.e. none of its members can be expressed in terms of the others with the help of Sheffer's stroke. S should also be *complete*, i.e. every (scientific) proposition should be expressible in terms of the members of S. It is not necessary to assume that S is unique. This definition would be adequate for symbolic purposes though so far no one has produced a useful set, S, of verbally expressed atomic propositions.[22])

The connectivity of the network would now be very high. It would have one or more vaguely tree-like substructures but with innumerable cross-connections, rather like a complete nervous system. In fact it may serve as a picture of a comprehensively stocked scientific brain. It would also resemble an organization of people, with the strength of the association between a pair of nodes corresponding to the amount of information that flows between a pair of people. Difficulties in organizing people for any project depend largely on the fact that the project cannot be logically organized in the form of a tree. This is more than an analogy when the project is a university, because the organization of a university ought to look like the knowledge network viewed from a distance.

The network of propositions is the fine-structure network; viewed from a short distance away it looks like a network of documents as considered by Fano[7] from the point of view of the retrieval of recorded information; and still further away it looks like the structure diagram of a university or of the Universal Decimal Classification.

I have been talking as if the nodes formed clumps or ganglia, but really the network is topological, and a clump needs a topological definition. Given a subset of nodes we could define its clumpiness as say

$$\min_i \sum_j |Z_{ij}|^{-2},$$

where the Z_{ij} are the impedances. A clump or ganglion is a large subset of nodes with a large clumpiness. A document usually corresponds on the whole to one or more clumps of scientific propositions.

Imagine a particle performing a random walk on the knowledge network with the probability of traversing a road depending on the strength of the association. In the long run the particle will be at each node for a certain proportion of the time (since we can safely assume that the network is connected). Then a possible recipe for wide learning is to allocate one's time in these same limiting proportions. This recipe could be applied either to the document network or to the propositional network. A possible desideratum for the definition of the strengths of the associations would be that the two recipes (and all analogous ones) should be consistent with each other.

All this is only pseudo-quantitative. It would be very difficult to make it properly quantitative. It represents an idealized form of mechanized knowledge in vague general

terms, and resembles Bush's mythical Memex machine.

In practice, a person's reading actually resembles a randomly moving particle. But some of the nodes act as centers of attraction partly because of the advantages of specializing. The impedances leading into these nodes are much smaller than those leading out. This may be the main thing that distinguishes the specialist from the generalist. Also in practice the motion is Markovian rather than strictly random: when a road is traversed its impedance is lowered and then slowly increases but usually never gets as high as it was originally.

Even the generalist has to do some specializing, otherwise he would not learn the true nature of scientific work. He needs to know everything about nothing as well as knowing nothing about everything.

This network model of knowledge leads as a corollary to the importance of general principles, because each general principle is a node with a lot of connections (associations).

There are many hints, which I shall not discuss, concerning the use of libraries and abstracting journals. There is a good account by N. G. Parke.[5] It is also important to be able to read both fast and slowly, changing speed according to needs. Fast reading would be possibly facilitated by having books printed with alternate lines running from right to left, since the eye would then not have so far to travel. This may be called boustrophedon printing (like an ox ploughing a field). The method was used in early Greek inscriptions. An increased size of alphabet, as suggested by Bernard Shaw, would also save reading time and printing and storage costs, but here too the capital cost would be high.

In mathematical printing, the reader's physical movements could be decreased by repeating formulae, and by printing symbols in the margin on their first occurrence.

My brother, A. J. Good, once made a useful suggestion about learning. It was that after reading a book you should read through the table of contents several times.

I have been talking about acquiring existing knowledge. I do not wish to imply that the emphasis given to different scientific subjects is already optimal. If the purpose is to *extend* knowledge then, in the above network model, the strengths of the associations may be replaced by what they *ought* to be instead of what they happen to be. If the greatest happiness of the greatest number is the criterion, there should, for example, be far more research on a science of tastes.[17] It may help to suggest a name, say *geistics* (from γευστικος) or *saporology* (a hybrid but perhaps better-sounding name). Without any increase in world food production the total enjoyment of it may be capable of a big increase. There are so many unique tastes that it is clear that taste-space is at present only thinly filled and many new tastes remain to be discovered.

Closely connected with this question of new fields for research is the fact that there seems to be no scientific periodical (of the ten thousand or so that are published) that is devoted to the publication of half-baked ideas. Did Gauss, Poincaré, Hilbert, or Einstein keep notebooks of half-baked ideas and if so where are they? The main communication of half-baked ideas is through science fiction and personal contacts. Bertrand Russell recently said that the anticipations of science fiction are much more intelligent than the expectations of statesmen. The Manchester Joint Research Council in 1950-53 said that personal contacts are much more important than the printed word. Will this be so true when *Half-Baked Ideas* is published?

It is time now to ask how much a man can "know" in effect with the help of a desk-aid.

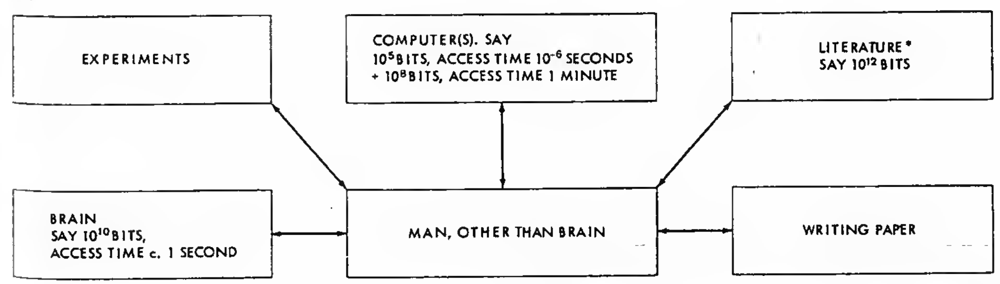
Imagine a man seated at a control panel, designing aircraft. Part of the panel could give control of a wind-tunnel and of other experimental work. This part of the panel may simply be a telephone. Another part would give control of one or more computers, with automatic programming. A third part would give quick access to the literature.

In the diagram of Fig. 1 everything communicates both ways with the "decerebrated man," and in no other way.

If the writing paper were replaced by suitable digitalized information, operated by means of a keyboard, then it could be transferred into the box marked *literature*. It could also be transferred without digitalization, but it would need a digitalized tag as in the Rapid Selector.[9]

Some of the experiments would be very expensive and one of the main functions of the man is to decide when to

Figure 1



*The Bush-Shaw Rapid Selector[9] will cope with 10^{10} bits, access time 1 minute. It should perhaps be combined with Zatocoding.[26]

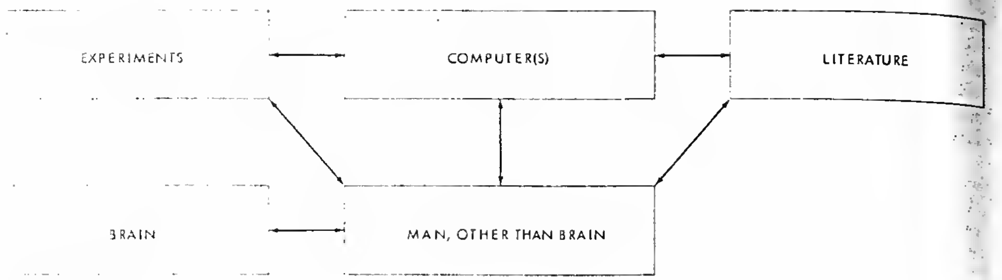


Figure 2

launch these expensive experiments. The time to make these decisions is, roughly speaking, when relevant information can be expected to come in slowly. This is a sort of general principle for making decisions. Without the computer and without rapid access to the literature the decisions will be made using less information. I expect you have all had the experience of requesting a book from a library, and when you get it hardly remembering what you wanted it for.

The set-up could be modified by allowing the computer to communicate directly with the experiments and with the literature. It could not communicate directly with the brain except by extra-sensory perception. We should then have the set-up shown in Fig. 2.

The complete system could be a lot more effective than a better man without aid. There is nothing new in this situation; a man with a race-horse can sprint faster than any athlete.

The computer is now seen to be in competition with the man. If the computer were good enough the man could go home. A firm called IBP, International Business People, would then grow up. It would be staffed by robots only. At their Symposia they would discuss whether people could think.

To come down to earth we may ask what are the probable new advances in consulting the literature in the near future? They do not all depend on mechanical aids. I should like to discuss some of them briefly under seven headings.

• 1. *Libraries*

These can of course be improved by orthodox methods, by simply spending more. There could be more libraries with more books and more staff, and with more rapid exchange of books between libraries. If books could be printed on thinner paper, at least for a part of the printing of each edition, then the problem of space in libraries would be partly solved. There may be some scope here for more chemical research concerning paper-making.

It would be convenient if each book could have attached to it a collection of all its reviews. There is some danger here though. One of the reviewers of a book by C. E. M. Joad admitted privately that he gave the book a scathing review although he thought it was a good book. He said it was more than his job was worth to praise the book in print. Such a dishonest review needs less publicity, not more. Unless of course it is known to be bogus.

• 2. *Abstracting journals*

It would be very useful if scientific abstracting journals would produce more cumulative indexes, especially author indexes with the titles of the articles attached. This would be a simple IBM sorting job; perhaps the Government should subsidize it.

It would also be very useful if the abstracts themselves could be re-sorted by subject, to cover say periods of five years and twenty years, and printed up. The microcard system does this to some extent but each recipient has to do his own sorting. You might drop them on the floor after eight years of sorting and have to re-sort them.

• 3. *Photostats*

These should be more readily accessible and at lower cost. Authors of papers should give the full range of page numbers in their references to facilitate the requisitioning of photostats. I know that the London Science Museum would support this, because I have asked them.

• 4. *"Micromicrofilms"*

The first question is how soon will it be possible to get linear reductions of a few hundred economically,[9,10] and what would it cost to put the whole of the Science Museum library, or the Fine Hall mathematical library on your writing desk? Could a micromicrofilm reader be developed that would make ready access possible?[27] Could copyright difficulties be overcome? Could the ordinary index cards of the libraries also be micromicrofilmed annually and distributed? Would the new fast printers being developed for printing 10,000 lines per minute (for the Bureau of Old Age and Survivors Insurance) be a suitable device for this annual distribution of the index? All this would be more useful than it may seem at first, because in the comfort of his study a scholar would be prepared to learn and make use of far more elaborate indexing methods than he can usually tolerate in a public library.

• 5. *Incentives*

I mentioned incentives before, but they are relevant again in this discussion of plans for the near future. For example, the incentive to mechanize is much higher in the United States than elsewhere, because labor costs are higher. Should referees of articles be paid, so as to make it possible to fine them for keeping manuscripts too long? Should technical papers written in the Civil Service contain, besides the author's signature, acknowledgments for help received?

• 6. *Linguistic difficulties*

This includes difficulties arising out of bad exposition. Should each member of an audience at a lecture have a knob to turn to indicate his degree of understanding, the total current being presented to the lecturer on a dial?[11,31] Should science students be given lessons in technical exposition and in technical reading, and who by? Incidentally a decimal classification of rules for writing informative English exists.[12]

Very great help could be given to readers both of their own language and of foreign languages by means of better technical dictionaries. What is needed is up-to-date specialized dictionaries.[35] A routine for compiling these dictionaries would be via the abstracting journals. On the first occurrence of a technical term in an abstracting journal it should be accurately defined in a footnote. (If it is a vague term its degree of vagueness could be accurately specified.) A cumulative index of the defined terms would be necessary, and cumulative dictionaries could then be compiled. These dictionaries would sell like hot cakes, so that the expense may be defrayed. (See also Ref. 28, pp. 16-18.)

It should be one of the explicit responsibilities of referees to judge whether new terminology was useful, or adequately self-explanatory. Stuart Chase made a naughty remark about scientific vocabulary. "Some professors seem to feel that if they can only get a terminology which is dense enough, they have somehow achieved the scientific method. All they have done is to shatter the communication line."[15]

How about foreign languages? It may be worth holding in mind that when you have difficulty in understanding a foreign article, you may be less to blame than the author. But assuming the exposition to be adequate, there are still difficulties, the main one being vocabulary, just as it is when trying to understand another specialist talking English. It would be helpful to have frequency lists of specialized vocabulary in each of the major languages. You could then learn the words in frequency order so as to maximize the expected utility per hour spent in learning vocabulary. The compilation of these specialized lists would be a very large IBM sorting job. There is some interesting statistical theory connected with the compilation of such lists.[13,14]

I can hardly leave this question without referring to mechanical translation. This is a field of work that seems especially appropriate for UNESCO.[25] Perhaps they should spend a much larger proportion of their funds on it, and especially on the invention of an unambiguous intermediate language. This leads me to my last heading.

• 7. *Datum handling and datum conversion*

When print is set up by means of a keyboard it would not be at all expensive for a digital magnetic tape, or its equivalent, to be prepared at the same time. All printers of books and periodicals could and should do this. These tapes would then be useful for the following purposes:

a) For sending abroad for reprinting. Note how cargo handling can be replaced by datum handling.
b) For other reprinting in type of different size, or for a different number of words to the line.
c) For later printing on specially thin paper, or for other reprints after the printed type pages have been broken up.
d) To speed up the production of a second edition.
e) For conversion into Braille.
f) For conversion into microfilm via a cathode ray tube display.
g) For conversion into micromicrofilm via an array of cathode ray tube displays.
h) For mechanical translation.
j) For inserting easier synonyms in brackets for the benefit of all readers, especially foreign ones. This might be a part of a more general and difficult project for translating articles from English into English, but this more difficult job may be better done by young research students via a central bureau.
k) For re-sorting by subject when the book deals with several subjects.
l) For indexing, possibly for a joint index with several other books.
m) For compiling the cumulative dictionaries of specialized vocabularies mentioned earlier.
n) For compiling the frequency lists of vocabulary also mentioned earlier.
p) For boustrophedon printing.
q) For conversion into simplified spelling. (When a bill in favor of simplified spelling was considered in the British House of Parliament it was only just rejected.)
r) For conversion into a larger alphabet.

There are also datum-conversion jobs that would be required merely because different printers may use different types of magnetic tape, or punched tape or cards, or just plain print! If there are n different media then there may be as many as $n(n-1)$ distinct datum-conversion jobs. Perhaps this problem can be rationalized, as in mechanical translation, by having an intermediate electronic medium. Then only $2n$ distinct types of machine would be required for datum conversion.[36]

In conclusion I should like to refer to some sentiments expressed in the editorial of *Nature* recently.[16] It said that the only way to meet the challenge of communication inherent in the diversity of the natural sciences is creative thinking, and also the type of environment provided by the great universities and the great research institutes.

"From such environments, comprising communities of investigators, working together in a common mode but in divergent fields, in continuous converse, in sympathy and in rivalry, without predetermined goal, without overcommitment as a body to any given sector or to any one approach to the natural world, have come a goodly proportion of the real conceptual advances which have proved to be landmarks in the history of science."

That is a fine piece of prose for a scientific periodical, but let's not forget the apparent exceptions. Newton's best work was possible because Cambridge University was closed down during the Great Plague and there have been plenty of other lone workers, though perhaps at some time in their lives they all had the sort of environment mentioned. Among them I think were Galois, Heaviside, Einstein, Dirac and Eddington. So let's pay a reasonable proportion of people for doing nothing, without bombarding them with too much information.

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The following references are also highly relevant and have been added in proof:

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Channels with Side Information at the Transmitter

Abstract: In certain communication systems where information is to be transmitted from one point to another, additional side information is available at the transmitting point. This side information relates to the state of the transmission channel and can be used to aid in the coding and transmission of information. In this paper a type of channel with side information is studied and its capacity determined.

Introduction

Channels with feedback[1] from the receiving to the transmitting point are a special case of a situation in which there is additional information available at the transmitter which may be used as an aid in the forward transmission system. In Fig. 1 the channel has an input x and an output y.

There is a second output from the channel, u, available at the transmitting point, which may be used in the coding process. Thus the encoder has as inputs the message to be transmitted, m, and the side information u. The sequence of input letters x to the channel will be a function of the available part (that is, the past up to the current time) of these signals.

The signal u might be the received signal y, it might be a noisy version of this signal, or it might not relate to y but be statistically correlated with the general state of the channel. As a practical example, a transmitting station might have available a receiver for testing the current noise conditions at different frequencies. These results would be used to choose the frequency for transmission.

A simple discrete channel with side information is shown in Fig. 2. In this channel, x, y and u are all binary variables; they can be either zero or one. The channel can be used once each second. Immediately after it is used the random device chooses a zero or one independently of previous choices and with probabilities 1/2, 1/2. This value of u then appears at the transmitting point. The next x that is sent is added in the channel modulo 2 to this value of u to give the received y. If the side information u were *not* available at the transmitter, the channel would be that of Fig. 3, a channel in which input 0 has probabilities 1/2 of being received as 0 and 1/2 as 1 and similarly for input 1.

Such a channel has capacity zero. However, with the side information *available*, it is possible to send one bit per second through the channel. The u information is used to compensate for the noise inside by a preliminary reversal of zero and one, as in Fig. 4.

Figure 1

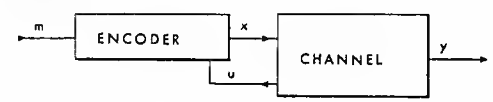

Figure 2

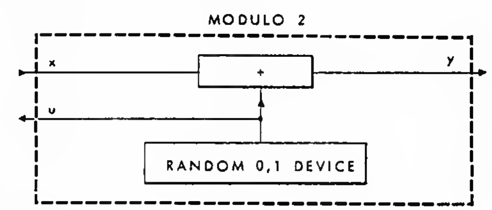

Figure 3

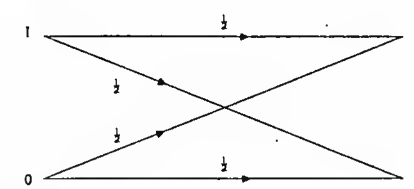

Figure 4